Available online at www.sciencedirect.com

ScienceDirect

Materials Today: Proceedings 11 (2019) 1094–1101

materialstoday: PROCEEDINGS

www.materialstoday.com/proceedings

I2CN_2018

Experiment on carbon dioxide removal from flue gas

Nixon Johny[a]*, Murali T R[b], Manu Mathew P S[c], Arun Raj A[d], Sukesh O P [e]

[abc]*UGscholar,Dept of Mechanical Engineering, Jyothi Engineering College,Cheruthuruthy,Thrissur,Kerala,678531,India*

[de]*AssistantProfessor,Dept of Mechanical Engineering, Jyothi Engineering College,Cheruthuruthy,Thrissur,Kerala,678531,India*

Abstract

Reducing CO_2 emissions for addressing climate change concerns is becoming increasingly important as the CO_2 concentration in the atmosphere has increased rapidly since the industrial revolution. Carbon capture and storage is the process of capturing waste carbon dioxide (CO_2) from large point sources, such as fossil fuel power plants, transporting it to a storage site, and depositing it where it will not enter the atmosphere, normally an underground geological formation. The aim is to prevent the release of large quantities of CO_2 into atmosphere. This paper aims at manufacturing of a simple and useful unit of capture the carbon dioxide. The air with carbon dioxide is made to flow through the reaction chamber using an axial flow fan and NaOH is sprayed using a nozzle. The NaOH reacts with CO_2 and form Na_2CO_3, and is collected in a tray. The maximum absorption rate of CO_2 is found to be at NaOH solution molar concentration of 5.

© 2018 Elsevier Ltd. All rights reserved.

Selection and/or Peer-review under responsibility of International Multi- Conference on Computing, Communication, Electrical & Nanotechnology: Materials Science.

Keywords: Carbon capture; NaOH solution; Molarity; Efficiency;

* Corresponding Author ,Tel:+91 9061596399

E-mail address: nixonjohny1@gmail.com

2214-7853 © 2018 Elsevier Ltd. All rights reserved.
Selection and/or Peer-review under responsibility of International Multi- Conference on Computing, Communication, Electrical & Nanotechnology: Materials Science.

1. Introduction

The awareness and investigation for reducing CO_2 emissions has increased due to the concern over the increased concentration of CO_2 in the atmosphere and its effect on global climate change [1]. The global warming and greenhouse effect have become serious global environmental issues. The main reason for all these problems are carbon dioxide produced in the energy utilization and emitted directly by human beings [19]. Therefore, the stability, safety and environment acceptability of CO_2 capture and storage (CCS) technologies have been paid worldwide attention.

In absorption method, absorbent is important. In recent years, some researchers found that aqueous ammonia seems to be an alternative and promising absorbent for removing CO_2 from flue gas [3].As from the previous researches carbon dioxide can be separated out of air or flue gas with absorption, adsorption, or membrane gas separation technologies. Absorption, or carbon scrubbing, with amines is currently the dominant capture technology. Membrane and adsorption technologies are still in the developmental research stages, initiating primary pilot plants in the near future. Metal- Organic Frameworks (MOFs) are a novel class of materials that offer promise for carbon capture using adsorption technologies.

Post-conversion capture involves separation of CO_2 from waste gas streams after the conversion of the carbon source to CO_2 – for example, via combustion of fossil fuels or digestion of wastewater sludge. It can be used to remove CO_2 from power plants, production of ethylene oxide, cement, fuels, iron and steel as well as biogas sweetening and some other industries [4]. Post-conversion capture is also known as post-combustion capture when used in power plants [5]. Pre-conversion capture refers to capturing CO_2 generated as an unwanted co-product of an intermediate reaction of a conversion process [6]. Some examples include the production of ammonia and coal gasification in power plants [4, 5, 7]. In ammonia production, CO_2 that is co-produced with hydrogen during steam reforming must be removed before the ammonia synthesis can take place –for these purposes absorption in MEA is commonly used [4,8]. Similarly, in an integrated gasification combined cycle (IGCC) power plant, CO_2 must be separated from hydrogen.

In the research, synthesis of Nitrogen-doped micro porous activated carbon adsorbent was done by a self-template method with KOH as the porogen agent at pyrolysis temperatures of 600,700 and 800 ºc[2]. However this method has disadvantages such as high cost for pure chemicals used in synthesis process [2].The Adsorption of CO_2 and N_2 in nano-porous BEA having SiO_2/Al_2O_3 method is very promising in the field of separation of CO_2 from flue gas. CO_2 sorption is observed to show higher sorption capacity than N_2 in all cation exchanged zeolite samples [9]. The adsorption capacity of CO_2 and N_2 are increased in these type of zeolites, On exchanging the BEA(25) with various cations, Li^+, K^+, Cs^+, Ca^{2+}, Sr^{2+}, and Ba^{2+}[9]. The relatively high costs of the chemicals are a major drawback of these methods.

Carbon dioxide adsorbs to a MOF through physisorption or chemisorption based on the porosity and selectivity of the MOF leaving behind a Greenhouse gas poor gas stream that is more environmentally friendly. The carbon dioxide is then stripped off the MOF using temperature swing adsorption (TSA) or pressure swing adsorption (PSA) so the MOF can be reused. Adsorbents and absorbents require regeneration steps where the CO_2 is removed from the sorbent or solution that collected it out of the flue gas in order for the sorbent or solution to be reused. Monoethanolamine (MEA) solutions, the leading amine for capturing CO_2, have a heat capacity between 3-4 J/g K since they are mostly water.[20][10] Higher heat capacities add to the energy penalty in the solvent regeneration step. Thus, Low heat capacities and heats of adsorption are desired to optimize a MOF for carbon capture. Also, high

working capacity and high selectivity are desirable in order to capture as much CO_2 as possible from the flue gas. However, there is an energy trade off with selectivity and energy expenditure.[11] As the amount of CO_2 captured increases, the energy, and therefore cost, required to regenerate increases. A large drawback of using MOFs for CCS is the limitations on their chemical and thermal stability.[12] Capture is attributed to about two thirds of the total cost of CCS, making it limit the wide-scale deployment of CCS technologies. To optimize a CO_2 capture process would significantly increase the feasibility of CCS since the transport and storage steps of CCS are rather mature technologies.[13]

A few engineering proposals have been made for the more difficult task of removing CO_2 from the atmosphere a form of climate engineering – but work in this is still not much developed. Capture costs are estimated to be higher than from point sources. But costs may be feasible for dealing with emissions from diffuse sources such as automobiles and aircraft.[14] Theoretically the required energy for air capture is only slightly more than for the capture from point sources. The additional costs come from the devices that use the natural air flow. Global Research Technologies demonstrated a pre-prototype of air capture technology in 2007.[15] .In spray drying system, the moisture on the droplets is evaporated gradually and at the same time the absorbents in the droplets react with impurities. Spray dryer is a well-known process in industry, e.g. for the production of ceramic precursors, and temperature-sensitive pharmaceuticals. This device has no wastewater products and can control CO_2 emission into atmosphere [16].

2. Experimental details

2.1. Experimental setup

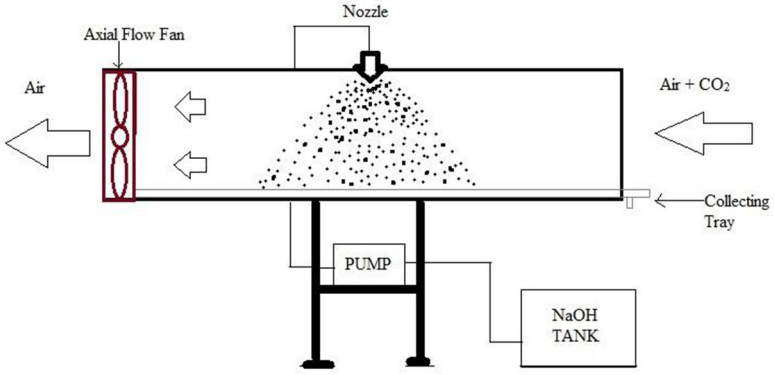

Fig.1.The above shown is the schematic diagram.

It mainly consists of a tank which is used to hold sodium hydroxide solution, any axial flow fan that helps to increase the flow of carbon dioxide, a nozzle which is used to spray the solution and a collector tray which is used to collect the precipitated sodium carbonate as shown in figure.

2.1.1. Axial flow fan

An axial fan is a type of a compressor that increases the pressure of the air flowing through it. The blades of the axial flow fan force air to move parallel to the shaft about which the blades rotate. In other words, the axial flow is axially in and axially out, linearly, hence their name. All the designing in an axial fan revolves around the design of the propeller that creates the pressure difference and hence the suction force that retains the flow across the fan.

2.1.2. Nozzle

A nozzle is a device designed to control the direction to control the direction or characteristics of a fluid flow (especially to increase velocity) as it exits (or enters) an enclosed chamber or pipe.

2.1.3. Pump

A pump is a device that moves fluids or sometimes slurries, by mechanical action. Pumps operate by some mechanism (typically reciprocating or rotary) , and consume energy to perform mechanical work by moving the fluid. The figure 2 shows the Experimental setup and includes all the components mentioned above.

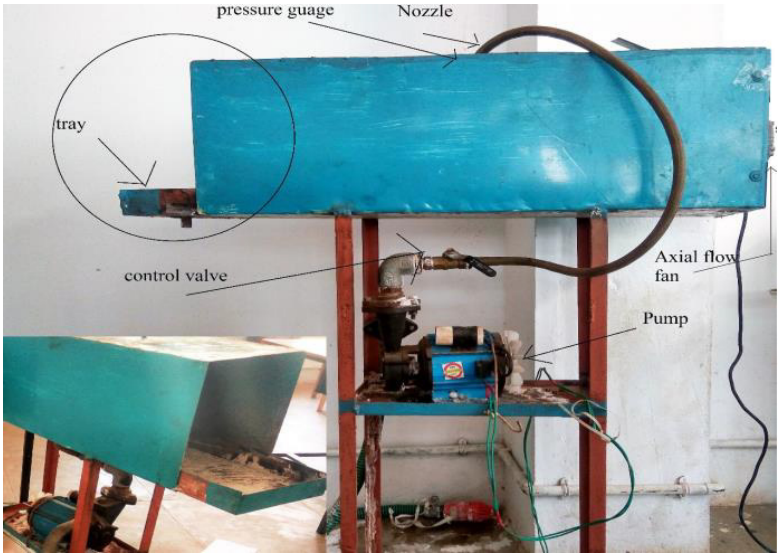

Fig. 2. Experimental Setup

2.2. Experimental procedure

NaOH pellets was mixed with water to form NaOH solution of required normality. The solution was left undisturbed for a duration of 2 minutes so that the heat produced due to the reaction was put out. The solution was then poured into the NaOH tank. The baking soda and vinegar are used to produce the required amount of CO_2 and the setup is placed inside the reaction chamber. After that, experiment was conducted and solution formed was collected in a tray. The sample is collected from the tray and is titrated for the estimation of carbonate thereby the amount of carbon dioxide captured.

2.2.1. Basic Reaction

$$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O \ldots\ldots\ldots\ldots \quad (1)$$

This paper relates to the capture and storages of carbon dioxide from where ever it is available and then making it to react with sodium hydroxide solution stored in a chamber to form sodium carbonate. Flue gases, mostly from the industries enter this chamber of NaOH for the reaction to take place. Flue gases contain mostly of carbon dioxide and other gases. These gases are a main source of greenhouse effect. NaOH is pumped continuously to the carbon dioxide chamber with the help of a pump through a tube. The reaction product is settled down on the tray which is placed below of the chamber. The efficiency of this equipment is defined as the ratio of amount of carbon dioxide captured to the amount of carbon dioxide supplied.

Therefore % Efficiency= (CO_2 output-CO_2 input)/ CO_2input

Molarity (M) is defined as the number of moles of solute per litre of solution.

Molarity= moles of solute/liters of solution

2.3. Results and discussion

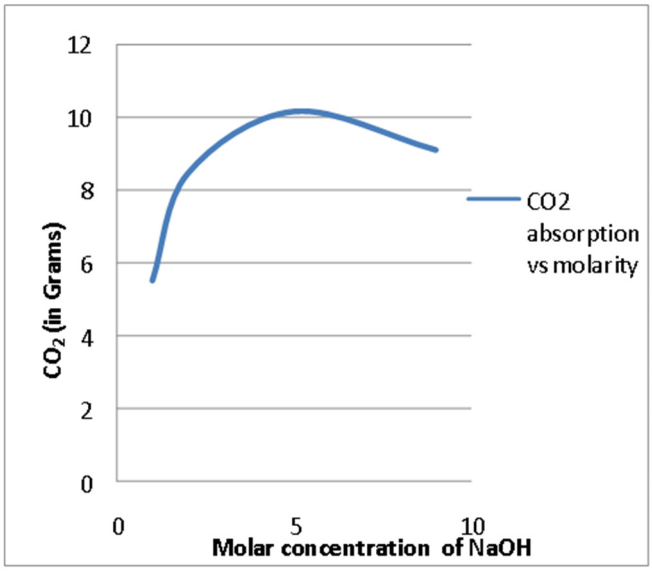

Fig. 3. Variation of CO_2 absorption with Molarity.

The figure 3. shows the variation of absorption of $CO_2$with respect to the variation in molar concentration of NaOH and the maximum absorption of CO_2 is for molar concentration 5. Further increase in concentration tends to decrease the absorption rate, may be due to increased viscosity and drop size [17].

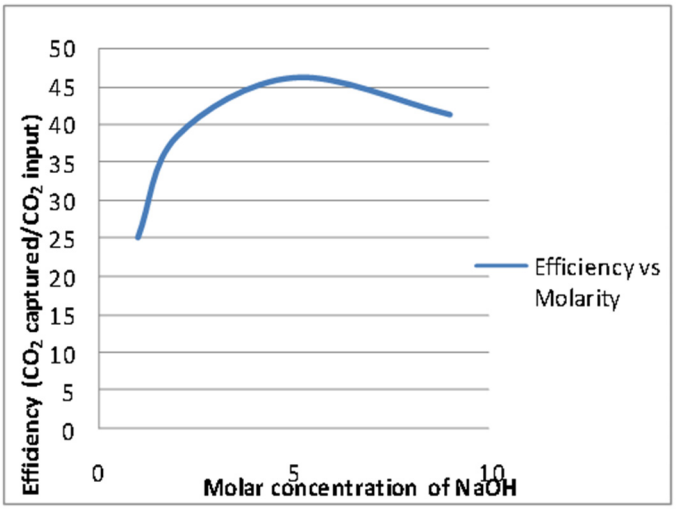

Fig. 4. Variation of Efficiency with Molarity

The maximum efficiency is obtained for NaOH solution at 5 molar concentration (fig 4).Further increase in molarity decreases the CO_2 absorption rate, it may be due to increased viscosity and drop size [17]. Thus in this paper it is used NaOH solutions with different molar concentration (1, 2, 5 & 9) for this experiment.

The NaOH is sprayed using a brass nozzle with flow rate of 1.4 L/s for a unit time period. The amount of CO_2 at inlet is made from the reaction between Baking soda and vinegar. The reaction is as follows,

$$CH_3COOH + NaHCO_3 \rightarrow CH_3COONa + H_2O + CO_2 \quad \text{..... (2)}$$

Thus in this paper it is used 0.5 mole baking soda and corresponding acetic acid to form 22 grams (0.5 mole) of CO_2 at the inlet of the apparatus and made necessary precautions against leakage of the CO_2 at the inlet and sprayed NaOH solution. The reaction inside the chamber is as mentioned in above equation (1).

After that, collected a sample of solution formed, in a sterilized container for further research. Then the experimental apparatus is cleaned and repeated the same procedure for different molar concentrations of NaOH. The

samples collected were subjected to titration and found out the amount of CO_2 in each sample. Then calculated the whole amount of CO_2 formed in the reaction chamber using flow rate of nozzle .The CO_2 at inlet is found out by the equation (2) and the amount of CO_2 found out from the solution is tabulated as below in table 1.

Table 1. Shows the variation in amount of CO_2 supplied at inlet and CO_2 captured with respect to different molar concentrations of NaOH solution.

Trial number	Molar concentration if NaOH	CO_2 inlet (g)	CO_2 outlet (g)
1	1	22	5.54
2	2	22	8.46
3	5	22	10.15
4	9	22	9.10

3. Conclusion

- The carbon dioxide capture apparatus is eco-friendly and captures carbon dioxide from flue gas with a maximum efficiency 46.13%.
- The CO_2 absorption rate increases up to molar concentration of 5. Further increase in molarity decreases the CO_2 absorption rate, it may be due to increased viscosity and drop size [17].
- The total cost for the removal of CO_2 from 1 kg of flue gas is Rs 216, Regardless of the initial cost and electric charges of the apparatus.

The standard flue gas from an industry contain only 16% of CO_2 [18] by volume. Therefore to remove carbon dioxide from 1kg of flue gas requires total Rs 216. Regardless of the initial cost and electric charges of the apparatus, and subtracting the market value of Na_2CO_3 (which formed during the reaction).

References

[1] Sean I. PlasynskiandZhong-Ying Chen Review Of Co_2 Capture Technologjes And Some Improvement Opportunities Vol 45-4; 644-649

[2] Jun Wang, Rajamani Krishna, Jiangfeng Yang, KodandaPhani Raj, Shuguang Deng ―Nitrogen-doped porous carbons for highly selective CO_2 capture from flue gases and natural gas upgrading‖ , Materials Today Communications 4(2015) 156-165.

[3] GuoYincheng, NiuZhenqi, Lin Wenyi , ―Comparison of removal efficiencies of carbon dioxide betweenaqueous ammonia and NaOH solution in a fine spray column‖, Energy Procedia 4 (2011) 512–518

[4] IPCC. Special report on carbon dioxide capture and storage. New York: Cambridge University Press; 2005 (ISBN:92-9169-1190-4).

[5] B. Singh, A.H. Strømman, E.G. Hertwich, ―Comparative life cycle environmental assessment of CCS technologies‖, International Journel of Greenhouse Gas Control 5 (4) (2011) 911–921.

[6] OECD/IEA/UNIDO. Technological roadmap – Carbon capture and storage in industrial applications. OECD/International Energy Agency and United Nations Industrial Development Organization. Paris: OECD/IEA/UNIDO; 2011.

[7] M. Pehnt, J. Henkel, ―Life cycle assessment of carbon dioxide capture and storage from lignite power plants‖, Int. J. Greenhouse Gas Control 3 (1) (2009) 49–66.

[8] J.M. Farla, C. Hendriks, K. Blok, ―Carbon dioxide recovery from industrial processes‖, Clim. Change 29 (4) (1995) 439–461.

[9] Renjith S. Pillai, ElbyTitusc. "CO_2 and N_2 Adsorption in Nano-porous BEA Type Zeolite with Different Cations". Materials Today: Proceedings 2 (2015) 446 – 455.

[10] Kulkarni, Ambarish R.; Sholl, David S. (2012). "Analysis of Equilibrium-Based TSA Processes for Direct Capture of CO_2 from Air". Industrial & Engineering Chemistry Research. 51 (25): 8631–8645.

[11] Millward, Andrew R.; Yaghi, Omar M. (2005). "Metal−Organic Frameworks with Exceptionally High Capacity for Storage of Carbon Dioxide at Room Temperature". Journal of the American Chemical Society. **127** (51): 17998–17999. doi:10.1021/ja0570032.

[12] Plasynski, Sean; Lang; Willis, Richard (2007). "Carbon Dioxide Separation with Novel Microporous Metal Organic Frameworks". National Energy Technology Lab. Chem. Rev., 2012, **112** (2): 724–781. doi:10.1021/cr2003272.

[13] McDonald, Thomas M.; Mason, Jarad A.; Kong, Xueqian; et al. "Cooperative insertion of CO_2 in diamine-appended metal-organic frameworks". Nature. **519**: 303–308. doi:10.1038/nature14327

[14] Stolaroff, J. K. Capturing $CO_2$from Ambient Air: A FeasibilityAssessment , Thesis Carnegie Mellon University, 2006.

[15] First Successful Demonstration of Carbon Dioxide Air Capture Technology Achieved by Columbia University Scientist and Private Company. Earth.columbia.edu.

[16] YadollahHosseini, SeyyedHossein―A novel rate of the reaction between NaOH with CO_2 at low temperature in spraydryer‖, Petroleum 3 (2017) 51-55 http://dx.doi.org/10.1016/j.petlm.2016.11.006

[17] Joshuah K. Stolaroff David W. Keith Gregory V. Lowry , ―Carbon dioxide capture from atmospheric air using sodium hydroxide spray: Supporting Information‖ , Environ. Sci. Technol., 2008, 42 (8), pp 2728–2735 DOI: 10.1021/es702607w

[18] Y. Hu, S. Naito, N. Kobayashi, M. Hasatani ,―CO_2, $NO_x$and SO_2 emissions from the combustion of coal with high oxygen concentration gases‖ ,Elsevier ,Fuel 79 (2000) 1925–1932

[19] YuanchangPeng, Bingtao Zhao, Leilei Li (September ,2011),'Advance in post-combustion CO_2 Capture with Alkaline Solution:A Brief Review' , Energy Procedia 14(2012)1515-1522

[20] Herm, Zoey R.; Swisher, Joseph A.; Smit, Berend; Krishna, Rajamani; Long, Jeffrey R. (2011). "Metal−Organic Frameworks as Adsorbents for Hydrogen Purification and Precombustion Carbon Dioxide Capture". Journal of the American Chemical Society. 5664–56